Annual Review of PHENIX VTX Project
BNL, June 9-10, 2008

Panel members: T. Cormier (Wayne State Univ.), D. Lynn (BNL), B. Surrow (MIT), R. VanBerg (Univ. Pennsylvania), S. Zimmermann (LBNL)

Also attending: T. Ludlam (BNL, Convener), H. Marsiske (DOE), G. Rai (DOE)

Overview

The PHENIX Silicon Vertex Tracker (VTX) is designed to provide precision tracking at the inner radii of the PHENIX detector. The VTX capability, in combination with the existing Central Arm tracking detectors, is intended to provide statistical samples of open charm and open beauty decays through measurements of decay electron tracks displaced from the primary interaction vertex. The nearly full-azimuth tracking capability of this detector is also expected to be utilized in the measurement of high-p_T photon-jet correlations, where the photon is measured in the PHENIX EM calorimeters.

The cylindrical VTX array consists of four layers of silicon detectors. The inner two layers are made up with pixel devices, with 50μm by 425μm pixel size, developed for the CERN ALICE detector. The outer two layers consist of silicon strip sensors, using the strip-pixel technique of interwoven strip geometry to achieve a two-dimensional readout in a single layer of strips. The strip-pixel sensors are produced by Hamamatsu, and read out using the SVX4 chip developed at Fermilab. The project is an international effort. Japanese (RIKEN) and French (Ecole Polytechnique) collaborators are responsible for the pixel systems. The U.S. DOE project scope includes the strip layers, the mechanical structure, and the overall integration of the mechanical and electrical systems into the PHENIX experiment.

The DOE portion of the project was officially started in June 2007. The detailed scope of the project, including performance specifications of the final detector, a Work Breakdown Structure with costs, schedules, and management responsibilities, is spelled out in the Project Management Plan signed in June 2007. This review is the first Annual Review of this project. Some of the reviewers participated in the DOE Technical, Cost, Schedule and Management Review of this project in May 2006, prior to the project's approval.

The progress on the pixel sensors and electronics chain, which are not part of the DOE project scope, was summarized for the reviewers. The committee found this part of the project to be well advanced and progressing toward a timely completion.

The primary focus of this review was on the technical difficulties with the Read-Out Card (ROC) for the strip-pixel system, and the consequences of these difficulties. The ROC is a board to read out one strip-pixel sensor. It has twelve SVX4 chips (128 channels each) that are read out by a custom, digital ASIC: the Readout Chip Controller (RCC). The initial version of the ROC suffered from severe noise due to pedestal jitter. An internal review in July 2007, by the VTX project provided a number of possible modifications to fix the problem. A new version, called ROC3, became available for test in March 2008. Its performance was improved, but channel-to-channel pedestal jitter was still too large to meet the signal-to-noise specified in the Management Plan using only on-chip zero-suppression. A technique for off-board channel-by-channel pedestal corrections was developed, and in cosmic ray tests performed in May 2008 the system appears to satisfy the signal-to-noise requirement. However, at this review the committee was presented with several challenging issues regarding the ROC3 development:

- The completed board is difficult to assemble, and the performance of the single board tested may not be reproduced in a production run.
- The material thickness of the present board is substantially greater than the maximum (3.5% radiation length) specified in the Management Plan.
- The VTX project team has formed in internal Task Force to examine an alternative design using conventional strip sensors instead of the strip-pixel approach. (The strip-pixel sensors have already been purchased for the project by the Japanese collaborators.)
- The ROC effort has been delayed by one year, and is now on the critical path.
- The VTX group is not able to provide a sound estimate of the schedule and cost to complete the project until these issues are resolved. The group presented a plan to convene another internal review in August 2008 to examine further tests and studies of the ROC3 card, as well as studies of the conventional strip alternative, in an effort to define a path forward for the project.

The committee's extensive discussions, both in joint sessions with the VTX project team and in executive sessions, focused primarily on these issues, which are now critical for the project. The committee's comments and detailed recommendations are given in the sections below. The main recommendations from this review are:

1. *The review of sensor choice, tentatively scheduled for August 2008, should take place as soon as practical, with the full involvement of the PHENIX collaboration, as well as the cognizance of BNL management and DOE. The committee saw a baseline technical design for the strip-pixel approach that seems viable but challenging. The backup plan presented is still in its infancy. In order to advance the schedule, a firm technical decision on the strip-pixel vs. conventional strip readout must be made as soon as possible, but must be based on clear information from simulation, testing, and prototyping. Input to the discussion at the review must include quantitative studies of the impact of the material thickness of the VTX on the full scope of the PHENIX science program.*

2. *The VTX team and PHENIX management must work together to provide critically needed additional effort on simulation, electronics design, testing, and data analysis.*

VTX Mechanical Design

The committee is pleased by the status of this effort and the successful relationship to HYTEC, a commercial firm which is carrying out the carbon-based design work. The mechanical design team has established contacts to the LBNL carbon-composite shop led by Eric Anderson for the fabrication of the VTX mechanical support structure. We strongly support this step to profit from the experience the LBNL group has gained through the ATLAS inner tracking system.

The overall mechanical support structure appears to be in a good state. We do recommend separating as much as possible the PIXEL (layers 1 & 2) from the strip-pixel system (layers 3 & 4) due to uncertainties in the actual realization of VTX layers 3 and 4. This refers in particular to the staves for the strip-pixel layers as well as the mounting fixtures. The committee *strongly recommends* that the VTX group builds as soon as possible a full mechanical prototype ladder for the strip-pixel system and performs important mechanical and thermal tests, besides electrical tests, which will be discussed below.

Silicon sensors and electronics

<u>Overall:</u>
Good progress has been made on a grounding and shielding plan and with planning infrastructure services for the VTX detector. HV power supply selection is converging based upon careful testing of prototypes. Early consultation with the BNL safety committee on the proposed powering architecture is recommended, to avoid late changes to the plan.

The mechanical design seems to be in good shape and this progress should be encouraged to proceed without interruption.

The schedule presented by the collaboration showed that a completed two layer pixel detector might be available a little over a year from now. A full system test of the two pixel layers installed near the PHENIX detector on this time scale could be very useful. The committee heard, however, that an early installation of the pixel layers into PHENIX, in the fall of 2009, is probably not consistent with the overall operations schedule for RHIC and PHENIX.

<u>Pixels:</u>
The Pixel electronics chain is logically straightforward and takes advantage of the existing ALICE pixel readout coupled to a GOL via the PILOT asic. The very challenging part of this development was the extremely dense cabling requirement. Diligent work with potential vendors has produced an elegant (if not inexpensive) solution in the final form factor. The planned tests are likely to be sufficient to fully qualify the design for production.

Strip-pixels:
The schedule delay to date puts this part of the VTX project on the critical path and requires additional attention by both the VTX and the larger PHENIX collaborations.

Performance of the ROC3 is encouraging but needs additional samples to be fully convincing. Optimization of ROC3 assembly issues may include removal or change to bottom side of some decoupling capacitors and, perhaps, other design changes. Progress on understanding the decoupling requirements is expected in the next month or two.

Tests of the ROC3 with cosmic rays are giving a good initial idea of minimum ionizing particle (MIPs) levels. The planned beam test this summer should make both the MIPs level and efficiency measurements much more complete. This will help confirm the expected signal to noise and efficiency numbers using tracks from the planned telescope. Tests including a demonstration of real time (non- SVX4) pedestal subtraction would be useful in validating the present plans.

The ground and power planes used in the ROC3 are extensive and relatively thick, leading to a large mass of copper. Studies to examine whether this mass of copper can be reduced while maintaining performance are yet to be carried out. Any change in thickness or density (meshing) of the planes would have to be demonstrated in a prototype.

The RCC prototype was, unfortunately, not completely simulated prior to production and a relatively minor error in pad connections resulted. This error can be corrected at some significant expense on a small number of chips in order to allow early testing of a readout bus. Another option would be to use a small CPLD or FPGA to emulate the RCC.

The RCC logical design needs to be changed somewhat to adapt to using SVX4 data without real-time pedestal subtraction and to correct a few minor logic errors. These changes, backed by complete simulations, should be completed expeditiously. Radiation testing of the present design is also planned to verify the operation of the LVDS blocks after radiation. The expected dose is, however, low enough that the chosen 0.25 micron technology should not present a problem.

Recommendations:
The proposed stave design builds on the present ROC design but includes several additional features, some of which may prove challenging - small flex cables from the ROC to the readout bus; multiple sensors on one stave, interactions with the bus or the RCC chips, power distribution, tooling or cooling. An early test of a prototype stave is strongly recommended. To meet the planned schedule it would be very helpful to move to a more parallel (less sequential) mode of work. For instance bus cable design, RCC changes, etc. do not need to wait for other tests to proceed to completion. This electrical prototype is independent of the detailed mechanical prototype mentioned above.

The RCC should proceed to a next generation prototype as quickly as possible, waiting only to verify the radiation hardness of the LVDS block.

Tests of the present ROC3 with clocks at the intended operating speeds to verify the higher speed readout needed without pedestal subtraction should be carried out before the planned August 2008 review as this is expected to require only FPGA recoding. There is concern that the higher clock speeds will further reduce the signal-to-noise.

There is concern that there is not sufficient manpower to simultaneously address the strip-pixels and the backup pure strip approach. However, the strip approach remains the backup. One test to address sensor vs. readout differences that could be implemented easily is to mount one of the Atlas-Z strip detectors on a ROC3 board with an SVX4 chip. For the simplest test a fan-out would not be necessary, and one could bond only those SVX4 channels that can be bonded directly to the detector. Even this very simple system will test whether the ROC3 and complete chain can read out a strip detector without the pedestal problems seen with the strip-pixel.

The strip-pixels would benefit from additional effort on simulation, electronics design, testing, data analysis, and other aspects. We urge the VTX project to recruit additional resources to help with some or all of these tasks.

VTX Performance

As details of simulations were not given in the review presentations, the status of the VTX simulations is hard to evluate. It might very well be that various simulations are indeed available, but for the time being, we think it is important to clearly articulate the type of simulations that are needed to justify in detail the proposed layout and the accuracy of different measurements that can be achieved in Au+Au, d+Au and p+p collisions. The committee recommends the following studies. Item (b), regarding the material budget, should be addressed by the time of the proposed August 2008 review. Item (a), together with items (c) and (d) should be accomplished by spring 2009, in order to move the project forward along with progress on a full ladder test.

a) <u>Tracking performance:</u>

- Document the assumption on the simulation model that has been used, such as physics processes and detector simulations besides hand-calculations.
- Show the hit efficiency for each tracking layer in central Au+Au ($\sqrt{s}$=200GeV) and p+p ($\sqrt{s}$=200/500GeV) collisions a) for tracking from outside to inside with the existing PHENIX central tracking detector and b) from inside to outside without the existing PHENIX central tracking detector.
- What is the level of S/N for the strip-pixel system that is acceptable for the tracking with and without the central PHENIX tracking system?

b) <u>VTX material budget:</u>

- Document the level of details that has been included for each tracking layer and the mechanical support structure.
- To what extent has the impact of albedo particles been taken into account in simulations, such as albedo particles from the NCC?

- Show the VTX material budget as a function of pseudo-rapidity and azimuthal angle.
- What is the VTX material budget that is tolerable by the PHENIX collaboration as a whole: J/Psi program, non-photonic electrons and DCA resolution necessary for a successful discrimination of charm / bottom? It appears that the total material budget for the current VTX design is ~16% X_0. This is an issue that has to be addressed as soon as possible to allow for potential re-direction of efforts on the actual VTX layout for layer 3/4.

c) Photon-jet measurements / Jet measurements:

- What is the resolution of the jet pseudo-rapidity for jets for which only the VTX is used? How does this change when including the existing central tracking system? How is this dependent on p_T in particular for the case of VTX only tracking?
- What is the p_T reach of jet reconstruction in general for VTX only tracking?
- What is the efficiency for photon-jet reconstruction and therefore the impact on the accuracy of various observable measurements involving photon-jet measurements for an assumed integrated luminosity?

d) Heavy-flavor measurements:

- How is the DCA value of 50μm justified for various heavy-flavor measurements? What drives this number? How well can charm and bottom events really be separated?
- What is the status of the DCA resolution studies using the full VTX material thickness?
- Demonstrate the level of semi-leptonic electron reconstruction taking into account the impact of material thickness giving rise to conversion background.
- What is the efficiency for heavy-flavor type measurement and therefore what is the accuracy of various observable measurements for an assumed integrated luminosity such as R_{AA} and v_2 in Au-Au and d-Au collisions and A_{LL} in polarized p-p collisions?

While the committee feels that conventional strip detectors are certainly much better understood with numerous successful applications, it should be pointed out that care has to be taken when using back-to-back single-sided silicon strip sensors in a heavy-ion environment. A stereo angle of 90 degrees will result in large number of ghost hits. This needs to be carefully evaluated with simulations.

Generally, the committee *strongly recommends* the PHENX VTX group to actively seek help together with the PHENIX management outside the current VTX software team for additional support with this simulation work.

Cost, Schedule, and Project Management

Cost Performance:

An accounting of project expenditures accrued to date and the cost to completion and remaining contingency was presented. Although only modest use of contingency has occurred to this point, it was noted that a number of planned expenditures in the near future would make significant demands on contingency. An updated analysis of project cost-risk was not presented so it is impossible to give an accurate evaluation of the adequacy of the contingency reserve at this point. However, the committee generally felt that at this early stage of the project with a number of significant technical challenges still unsolved, the present reserve may be insufficient to complete the baseline.

Cost and schedule challenges:

In response to a number of technical problems, a task force has been formed to examine alternative detector technologies – strip-pixel versus conventional strip. The committee feels that a parallel approach that examines both technologies can be sustained for a short while but that there are insufficient project contingency reserves to allow the continued development of prototypes of both alternatives. In the short term, the committee advises continued aggressive work on the baseline, strip-pixel device, with a decision concerning the necessity for a change to conventional strip sensors as soon as possible. At the present time almost nothing is known concerning the cost and schedule implications of the contemplated change in detector technology however, it is clear that such a change – should it occur - will require a re-baseline of the project.

The committee is worried that the duplication of effort implied by at least some of the task force's work would dilute effort on the base-line project, which already appears to be suffering from lack of manpower. Project management is advised to be mindful of possible negative impact on the baseline schedule.

Project management issues:

The performance of the project management team in response to the events leading up to the formation of the task force mentioned above has given the committee some concerns as to the efficacy of the project management team. The present situation borders on a schedule crisis with significant uncertainty remaining at this late date as to the likely success of the baseline project. Even with the present serious threats to the schedule, it appears to the committee that the efforts of the project team remain largely serial rather than parallel in the development of the strip-pixel system.

In the committee's view, the project managers have been too slow in calling for extra resources from PHENIX and/or BNL to fill what appear to be holes in the project's ability to complete essential performance simulations and operate parallel technical prototyping and testing activities that would have helped keep the project on schedule.

The committee believes that a more aggressive attack on the technical issues surrounding the pixel-strip sensor was required almost a year ago when it became apparent that there were serious potential problems with the baseline design. Instead, the management approach was to continue to delegate authority to the subsystem manager level rather than implementing an active control of the work in participating institutions to ensure the sharpest possible focus on the few issues that that threatened the baseline.

The committee has gotten the sense that there is some concern within the project as to the choice of the base line design at this late date and that this is at least partially responsible for the formation of the task force. A review of the sensor choice which is tentatively scheduled for August should have the widest possible involvement from PHENIX so that the full collaboration has the opportunity to sign off on the VTX design.

PHENIX and the project management team needs to discuss with BNL and DOE exactly what changes in the current approach can be quickly implemented to ensure that the VTX baseline gets back on track.

Appendix

Agenda for PHENIX VTX Review
June 9-10, 2008

June 9

8:30- 9:00 Executive Session
9:00- 9:45 Introduction/Overview (30+15) Yasuyuki Akiba
9:45- 10:25 Strip-pixel test results (30+10) Rachid Nouicer
10:25- 10:40 Break
10:40- 11:20 Strip-pixel Status (25+15) Yasuyuki Akiba
11:20- 12:00 Conventional Strip Option (25+15) Abhay Deshpande
12:00- 12:30 Project Plan for Strip Sensors (15+15) Craig Ogilvie
12:30- 1:30 Lunch Break
1:30- 2:30 Pixel Status (40+20) Atsushi Takatani
2:30- 2:50 VTX Mechanical (15+5) Walt Sondheim
2:50- 3:10 Infrastructure and assembly (15+5) Robert Pak
3:10- 3:30 Electronics Integration (15+5) Eric Mannel
3:30- 3:45 Break
3:45- 4:30 Cost/Schedule (30+15) Craig Ogilvie
4:30- 6:30 Executive session
7:00 Dinner

June 10

9:00-10:30 Breakout session
Pixel Atsushi T
Strip-pixel Abhay D, Rachid N
Mechanics, Integration Walt S, Robert P
Project Management Yasuyuki A, Craig O
10:30-12:00 Report Writing
12:00- 1:00 Lunch
1:00- 3:00 Executive session continues
3:00 Close Out
3:30 Adjourn